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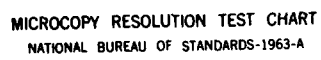
T-MOTOR TESTS WITH CYLINDRICAL GRAINS(U) FOREIGN  
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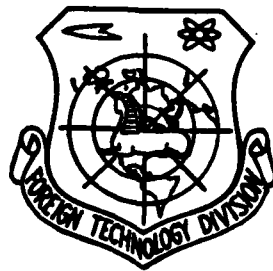
# FOREIGN TECHNOLOGY DIVISION



T-MOTOR TESTS WITH CYLINDRICAL GRAINS

by

K. Yeh



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## EDITED TRANSLATION

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### ABSTRACT

In this paper, some experimental results have been given for T-motor tests with cylindrical grains. These show that, within a certain boundary of grain geometry, the response function is independent of the combustion surface area of the propellant.

#### I. Experimental Conditions and Characteristics of Cylindrical Grains

The combustion chamber used in the experiment has an inner diameter of 5 cm, and inner length of 50 cm. As changes in the combustion surface area produce variations in pressure, the latter can be controlled to lie within the required range by switching to different combustion chamber nozzles with various throat diameters. The BYY-3 transducer for measuring the static pressure and the BPR-3 transducer for measuring the oscillatory pressure are installed separately at the two ends of the combustion chamber. One end of the cylindrical grains is glued to the compressed choke head of the combustion chamber by means of an epoxy resin mixture, and the other end is wrapped in cloths treated with a nitrate-based paint to ensure even surface combustion. The initial temperature of the grains is kept within the temperature range of 10-25 °C, and the equilibrium pressure of the acoustic energy growth section is controlled to lie between 50 and 80 kg/cm<sup>2</sup>. A double-lead-2 solid propellant is used in the experiment, and

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\*\*This work has been completed under the guidance of Prof.

P'eng Choayuen.

\*\*\*Numbers in margin indicate foreign pagination

black gunpowder is used for ignition. As the combustion surface area increases from  $65 \text{ cm}^2$  to  $228.6 \text{ cm}^2$ , the amount of ignition gun powder used is increased accordingly. A typical experimental curve as recorded on a SC-18 oscilloscope is shown in Fig. 1.

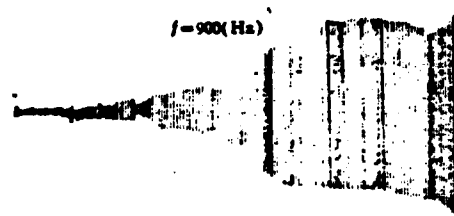


Fig. 1. A typical acoustic vibration growth curve

Using cylindrical grains in T-motors does away with the disadvantage of relatively large damping of end-surface grains, and that of generating residual propellant in annular grains. As the cylindrical grains have sufficient combustion surface area to create a great tendency for acoustic vibrations, the effect of the acoustic damping  $a_d$  on the actual value of the acoustic energy growth rate  $a = a_g + |a_d|$ , which produces a relatively large error in the measurement, becomes correspondingly small.

## II. Experimental Results and Analysis

The acoustic energy growth rate of the cylindrical grains can be expressed as:

$$a = \frac{4\gamma RLf}{s_1^2} C_1 [A_s + \bar{M}_s] \frac{S_{\mu}}{S_n}$$

where

$$A_s = \frac{\bar{u}_s/a_s}{\rho_1/\tau\rho_0} \quad \bar{M}_s = \frac{\bar{u}_s}{a_s} \quad C_1 = \frac{1}{S_n} \int_0^L \rho_1^2 \int dq dx \quad s_1^2 = \frac{1}{2} \int_0^L \rho_1^2 S_n dx.$$

Given the gas constant  $R$ , specific heat ratio  $\gamma$ , the inner length  $L$  of the combustion chamber, the measured frequency  $f$ ,

acoustical energy growth rate  $\alpha$ , and the  $C_1$  and  $\varepsilon_\ell^2$  under the given experimental conditions, one can calculate the value for  $A_b + \bar{w}_b$ . The major divisions of the combustion chamber and the vibration modes of pressure are as shown in Fig. 2. In the diagram,  $S_c = S_{c1} + S_{c2}$ . Making use of the continuity requirement on the wave motion and mass flow perturbation of the pressure at the radial position  $x = x_b$ , and introducing the dimensionless quantities  $\beta = 2x_b/L$  and  $K_1 = L\omega_1/2a_0$ , one can obtain the mathematical expressions for computing  $K_1$  and the pressure acoustic vibration modes  $\hat{p}_1$

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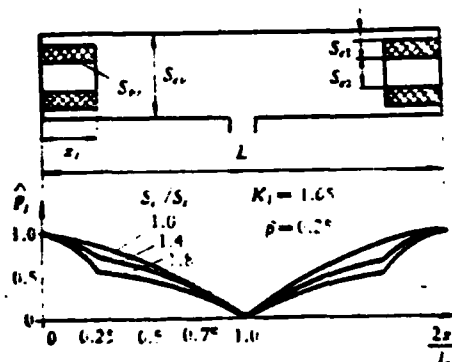


Fig 2. Simplified diagram of the combustion chamber and the acoustic vibration modes

$$\begin{aligned} (S_{c2}/S_c) \cos K_1(1 - \beta) &= \tan K_1\beta \\ \hat{p}_1 &= \cos K_1 2x/L \quad (\text{当 } 0 \leq 2x/L < \beta) \\ \hat{p}_1 &= \frac{S_c/S_{c1}}{\cos K_1(1 - \beta)} \sin K_1(1 - 2x/L) \\ &\quad (\text{当 } \beta < 2x/L \leq 1) \end{aligned}$$



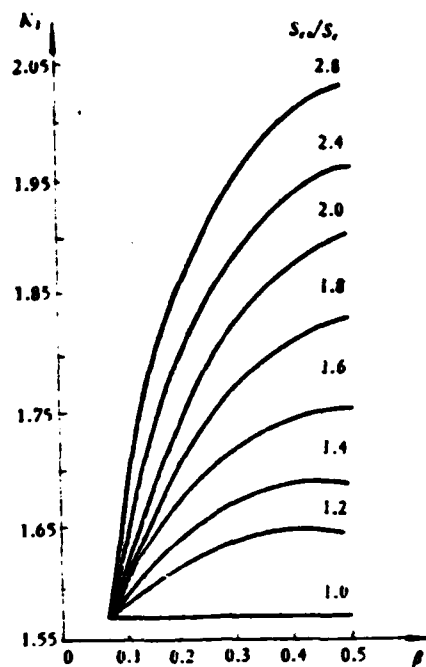


Fig. 3. Relation between the dimensionless frequency and the grain geometry

Fig. 3 shows the variation of  $K_1$  with the area of the combustion chamber passage and grain length. With respect to the present experiment, when the grain geometry is given by  $D/d = L_b = 38/14 = 30$ , ( $S_{c0}/S_c = 2.10$ ,  $\beta = 0.12$ ), one obtains from Fig. 3  $K_1 = 1.64$ . For the double-lead-2 propellant,  $\gamma = 1.21$ ,  $R = 31.67$ ,  $T_0 = 2500\text{K}$ . Therefore  $a_0 = \sqrt{\gamma R T_0} = 968 \text{ m/s}$ ,  $f = K_1 a_0 / \pi L = 1012 \text{ Hz}$ . Owing to heat loss and other damping factors, the actual measured frequencies lie within the range of 890-950 Hz.

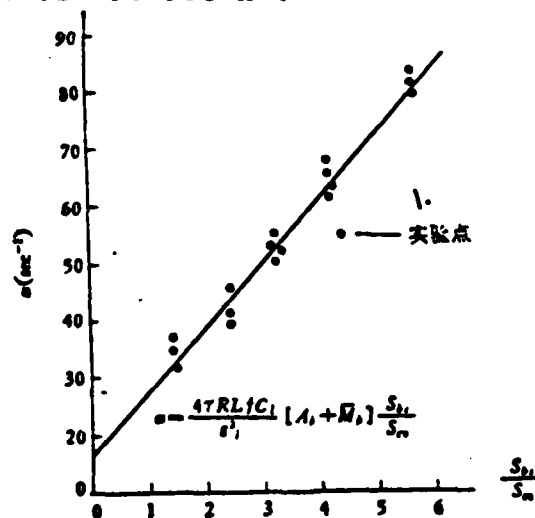


Fig. 4. Relation between acoustic energy growth rate and combustion surface area ratio

## 1. Experimental points

Knowing how  $K_1$  and  $\hat{p}_1$  vary, one can compute the magnitude of  $C_1$  and  $\varepsilon_l^2$  with respect to a specific combustion chamber structure. The variation of the experimentally measured acoustic energy growth rate with the combustion surface area ratio is shown in Fig. 4. Price's method has been adopted in the data analysis. It can be seen from the experiment that the linearity and repeatability of the curves for the acoustic attenuation section are far from being ideal. Undoubtedly, variation on the geometrical shape of the propellant and the flow of the mean flow produce a difference between the acoustic vibrational damping combination and that at the completion of the combustion. Fig. 5 shows the acoustic growth rate measured experimentally for 30, 40 and 50 mm grains, respectively. It can be seen that these characteristic curves possess good linearity and conformity.

When the grain geometry is given by  $D/d \text{---} L_b = 44/8 \text{---} 80$ , there appear regularly harmonics due to velocity coupling and serious distortion of the pressure oscillation due to the relatively high mean flow rate. In the course of the combustion, the area of the gas passage is enlarged, the mean flow rate decreases, and the oscillation curve tends to normal.

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There is a critical point above which the oscillation curve will be distorted by velocity coupling and excessive mean flow rate. Satisfactory pressure oscillation curves have been obtained in the experiment by changing the grain geometry from  $D/d \text{---} L_b = 44/8 \text{---} 80$  to  $38/14 \text{---} 70$ . This is why the maximum grain length has been taken to be 70 mm for this experiment.

## III. Conclusion

Nice linear relations between  $\alpha$ ,  $\beta$  and  $S_{bs}/S_{c0}$  can be obtained for a T-motor with cylindrical grains within certain limits set jointly by  $S_{bs}/S_{c0}$  and  $\beta$ . This proves that the pressure response function of the propellant is independent

of the combustion surface area. Outside of these limits, the resulting abnormality in the pressure acoustic field due to velocity coupling and high mean flow rate is serious. This places a restriction on the choice of values for  $S_{bs}/S_{c0}$  and  $\beta$  for T-motors. As a result, linear relationship between  $\alpha$  and  $S_{bs}/S_{c0}$  can only be obtained within limited ranges.

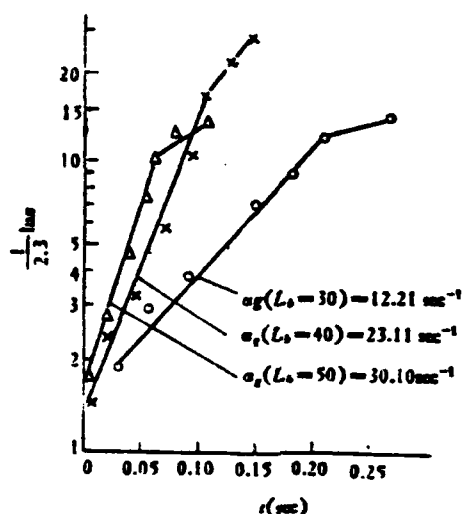


Fig. 5. Linear characteristics of the acoustic energy growth of grains of various lengths

#### Notations

- $a_0$  stagnation sound velocity
- $x$  radial displacement
- $q$  circumference of cylindrical grains
- $D$  outer diameter (mm) of grains
- $d$  inner diameter (mm) of grains
- $L_b$  length of grains (mm)
- $S_{bs}$  combustion surface area
- $S_c$  air passage area
- $S_{c0}$  cross-sectional area of combustion chamber
- $\omega_l$  angular frequency of oscillation
- $A_b$  combustion surface sonar
- $\hat{p}_t$  complex amplitude of pressure perturbation
- $\hat{u}_b$  complex amplitude of the velocity of the gas at the combustion surface

$P_0$  stagnation pressure  
 $\beta$  dimensionless grain length  
 $K_1$  dimensionless oscillation frequency  
 $\alpha_g$  measured acoustic energy growth constant  
 $\alpha_d$  measured acoustic energy damping constant  
 $T_0$  stagnation temperature  
 $z$  height of sound wave amplitude

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